TEACHWITHPORTALS™

Subject: Physics

Title: Terminal Velocity

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Grade Level: 9-12

Standards Met:

Physics Standards

Friction, Air Resistance

Next Generation Science Standards

HS.PS-FM Forces and Motion, performance standards (a) Plan and carry out investigations to show that the algebraic formulation of Newton's second law of motion accurately predicts the relationship between the net force on macroscopic objects, their mass, and acceleration and the resulting change in motion.

Science and Engineering Practices: Planning and carrying out investigations, Analyzing and interpreting data, Using mathematics and computational thinking, Constructing explanations and designing solutions, Developing and using models.

ACT Standards

Interpretation of Data – Translate information into a table, graph, or diagram (20-23), Determine how the value of one variable changes as the value of another variable changes in a complex data presentation (20-23)

Scientific Investigation – Predict the results of an additional trial or measurement in an experiment (24-27)

Time Needed: 60 Minutes

Objective(s): Demonstrate the effects of air resistance on terminal velocity

Summary: Students will be building a simple experiment to compare the terminal velocity of a cube and Chell. Lesson includes a brief investigation into the math behind air resistance and terminal velocity.

Vocabulary: Terminal Velocity, Friction, Air Resistance, Forces, Free Fall

Student Prerequisites: velocity, friction, forces

Teacher Materials Needed: None

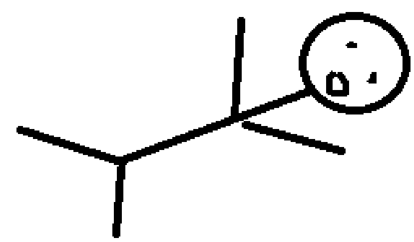
Student Materials Needed: Stopwatch

APERTURE LABORATORIES

This lesson plan was developed with the idea that the educator understands physics and the basics of Portal 2. *The lesson itself should flow from an introduction, into a main lab activity, and then finish with follow up questions and a homework assignment. The* ***Introductory Activity*** *section starts with questions to ask students at the beginning of class or in the class prior. The* ***Implementation*** *section gives instructions to the instructor as to how to set up the main lab activity. The* ***Closing Activity*** *section lists questions for students after they complete the main lab activity. The* ***Homework*** *section suggests questions to assign as homework after the lab. The* ***Grading Advice*** *section gives answers to all of the questions in the* ***Introductory Activity****,* ***Implementation****,* ***Closing Activity****, and* ***Homework*** *sections. I'm always looking for better lessons or ideas. If you have any questions or comments, please contact me at: cameron *dot* w *dot* pittman *at* gmail *dot* com.*

Introductory Activity:

1. Diagram the forces present on a falling skydiver.



2. Terminal velocity is the fastest an object will move solely under the influence of gravity. At terminal velocity, how will the vertical forces on a skydiver compare? Why?
3. What can a skydiver do to change their terminal velocity?
4. Compare and contrast the terminal velocity of a falling sheet of paper (non-crumpled) and a falling wad of paper (crumpled). How does the shape of the paper affect the way it falls?
5. An alien from Venus is visiting Earth. On Venus, the atmosphere is much thicker. Let's assume the strength of gravity on the Earth is about the same as it is on Venus (Venus' gravity is actually just a bit less). If the Venusian alien jumps out of a space ship and falls towards the Earth, how will their terminal velocity in Earth's atmosphere compare to their terminal velocity on Venus? Why?

Implementation:

1. (Recommended) Discuss the introductory activity questions first. Have students act out question 4 if necessary or if time allows.
2. Students will build a very simple infinite fall (two portals on top of one another).
3. Students should make the ceiling four panels high, so as to make it easier to count the number of falls.
4. Students will use a stopwatch to record the time it takes for a cube to make five full drops through the room at terminal velocity (hint: listen to the 'woosh' sound made by moving through a portal to figure out the number of falls). Students should wait a few seconds until it becomes clear the cube has reached terminal velocity. Fill out table 1 (see attached).
5. Repeat step 4 four more times.
6. Repeat steps 4-5 using Chell as the falling object.

Closing Activity:

1. Complete the calculations at the bottom of table 1.

2. How do the terminal velocities of Chell and the cube compare? Which is faster? Why?
3. Predict the terminal velocity of a flatter, lighter companion cube.
4. If you noticed a discrepancy between the terminal velocities, what reason might the game developers have for programming a difference?
5. Terminal velocity can be found by

   $$v_{terminal} = \frac{mg}{b} \qquad (1)$$

   where b represents the strength of the air resistance.
   a. What are the units of *b*?
   b. If the mass of an object increases, how does terminal velocity change?
   c. If air resistance is stronger, how does terminal velocity change?
6. What was the purpose of repeating our measurements five times?

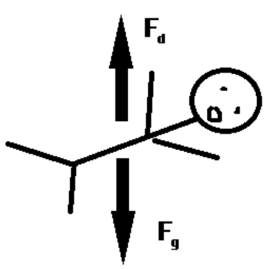
Homework:

Oh no! GLaDOS is trying to kill Chell again with deadly neurotoxin. In order to escape, Chell jumps down what looks like an infinitely deep pit and reaches terminal velocity on the way down. Let's assume that Chell has a mass of 50 kg and gravity within Aperture Labs is 9.8 m/s^2.

a. If the deadly neurotoxin flooding the air increases *b* from 3.2 N-s/m to 4.5 N-s/m, by how much will Chell's terminal velocity decrease?
b. How else could Chell slow herself down before reaching the bottom of the pit?

Grading Advice:

Introductory Activity:

1. 

2. The force of gravity and drag force equal each other at terminal velocity.
3. A skydiver can angle their body to minimize friction.
4. A wadded piece of paper feels less drag because it presents a smaller surface area to the air. A flat piece of paper presents a large surface area and feels much more resistance.

Closing Activity:

3. A flatter, lighter cube has more friction and would have a lower terminal velocity.

4. Different objects need to behave differently in a game in order for certain puzzles to work.

5. a. Rearrange equation 1 to find that

$$b = \frac{mg}{v_{terminal}} \qquad (2)$$

The unit for *m* is kg, *v* is m/s, and g is m/s², so the final unit for *b* will be: kg/s

b. Terminal velocity increases.
c. Terminal velocity drops.

Homework:

a. Starting with equation 1. Set b_1 = 3.2 N-s/m and b_2=4.5 N-s/m.

$$v_{terminal} = \frac{mg}{b} \tag{3}$$

$$\Delta v_{terminal} = \frac{mg}{b_2} - \frac{mg}{b_1} \tag{4}$$

Plug in and you get $\Delta v_{terminal} = -44 m/s$

b. She could increase her surface area by falling in a spread eagle position.

Additional Activities:

- If your students have already calculated *g*, you can determine *m*/*b* .
- Calculate error on student measurements.
- Replicate experiment using turrets or other kinds of cubes.
- If possible, change the force of friction and repeat experiment.

Data Collection Worksheet

Fill in table 1 with the amount of time it takes to make 5 full drops through a room at terminal velocity.

Table 1:

	Fall 1 (s)	Fall 2 (s)	Fall 3 (s)	Fall 4 (s)	Fall 5 (s)
Chell					
Cube					

Height of the room (units): ________________________

Average fall time (s):

Chell: ______________________

Cube: ______________________

Using $v = d/t$

Terminal Velocity (units/s):

Chell: ______________________

Cube: ______________________